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## Introduction

Urbanized areas have environmental features that may influence the development of low-enthalpy geothermal systems and the choice of the most suitable system type among the available. In this general context, the increasing implementation in several areas of the world of the open-loop groundwater heat pumps technology which discharge into the aquifer for cooling and heating buildings, could potentially cause, even in the short term, a significant environmental impact associated with thermal interference with groundwater, particularly in the shallow aquifers. An increased contact area between the dispersant system and the ground makes it possible to affect a greater volume of aquifer and, consequently, reduce the areal extent of the thermal plume that develops around the area of injection minimizing the time and the space needed for the disappearance of the thermal plume and the restoration of undisturbed temperature conditions. In order to investigate alternatives to traditional drilled water well for the re-injection and dispersion of water in aquifer downstream of the heat pump, we modeled with FEFLOW the possible reverse use of commercial draining gabions in various types of ground configuration, geometry and interconnection with systems of pre-fabricated vertical drains on a possible reliable test-site. The results highlighted that they can represent a good and efficient alternative for the groundwater dispersion in the aquifers.

## Material and Methods

In this general context, the increasing implementation in several areas of the world of the open-loop groundwater heat pumps technology which discharge into the aquifer for cooling and heating buildings could potentially cause, even in the short term, a significant environmental impact associated with thermal interference with groundwater, particularly in the shallow aquifers (Lund 2011).
The discharge of water at different temperatures compared to baseline (warmer in summer and colder in winter) poses a number of problems in relation to the potential functionality of many existing situations of use of the groundwater (drinking water wells, agricultural, industrial, etc.). In addition, there may be cases of interference between systems, especially in the more densely urbanized.
Normally “traditional” drilled vertical wells are used both for the withdrawing and for the re-injection into the aquifer. In most of the plants in fact, the re-injection in aquifer water occur through a simple gravity disposal in a normal well that is thus defined in terms of "re-injection". Through the screens of this well column, the water discharged into the well interacts with the aquifer, being in natural motion, and disperses gradually transferring downstream the heat in the aquifer producing a thermal anomaly in the immediate surroundings (thermal plume). This thermal anomaly upon interaction with the undisturbed aquifer (heat exchange between water and the solid matrix and hydrodynamic dispersion) gradually tends to decrease up to disappear and, consequently, the water discharged goes back to the natural undisturbed temperature after a certain time and after covering a given travel in the aquifer. This project aims to investigate alternatives to traditional drilled well for the re-injection and dispersion of water in aquifer downstream of the heat pump in order to optimize the dispersion system in terms of simplicity of implementation and installation, costs of implementation and management, hydraulic effectiveness of the dispersion and containment of the spatial and temporal thermal plume. In particular, it will be studied the possible reverse use of commercial draining gabions. The study will examine, through a phase of experimentation on a suitable site, the effectiveness of systems for the dispersion of the water in the aquifer which are alternative to the wells. To evaluate the subsurface environmental effects of the GWHP system, modeling study was performed using the finite-element FEFLOW® package developed by Diersch, 2005. The conceptual model has been simplified in two layers, layer 1 corresponds to the unsaturated zone and the layer 2 represents the unconfined aquifer that is two meters below Level 1. All two layers has been simulated using physical properties appropriate to the hydro-geology of the formations. A plan view of the area covered by the computational grid (about 3,000,000 m$^2$; 595,062 elements and 396,968

nodes). The horizontal dimensions of the model grid are 1500 m (N–S) and 2000 m (W–E). The average mesh spacing in the modeling domain is 54 m. It was refined to 0.30 m in the central area close to the wells to provide enhanced estimation of thermal plumes. We have simulated in the transient condition for 10 days and then assuming a summer period. In particular, they have been assumed two scenarios. First scenario (case A) corresponds to the condition of including in the model the well while second scenario correspond of including in the model the alternative method to the well, such as a drain gabion (case B).

All two scenarios involve a particular interest with regard to the model simulations is the areal extent and sustainability of the subsurface thermal plume developed around the injection well and around the drain gabion at the maximum flow conditions set out in the summer during the cooling operations. The initial groundwater temperature for layers 1 and 2 was set at 14.4°C. This temperature is nearly constant throughout the year.

Rainfall infiltration was not included in the calculations due to a lack of infiltration data and the characteristics of the model surface, which is mostly covered by buildings and roads and was therefore considered essentially impermeable (Baccino 2010). The unperturbed groundwater flow is stable throughout the year, based on groundwater level monitoring. Therefore, for the case A, the Dirichlet boundary conditions were set by fixing groundwater levels on the upstream and downstream surfaces. Instead for the case B, the temperature and the discharge of the upstream surface (inflow) was set equal to the downstream surface (outflow) and was set based on a flux Neumann condition.

The numerical simulations of heat transport within the aquifer were solved using transient conditions. The maximum value of injection temperature and injection discharge are 21.4 °C and 420 $m^3$/d.

## Results

The thermal plume of the case A is more narrow and long along the flow direction, while the thermal plume relative to the case B is more extended and wider (Fig. 1). The draining gabion therefore, is suitable for being considered as a recharge basin, this is why the isotherms are more extensive and less elongated along the flow direction.

## Conclusions

In this paper, the results highlighted that they can represent a good and efficient alternative for the groundwater dispersion in the aquifers. Increasing the contact surface area for the dispersion in the aquifer therefore can be an effective way to significantly reduce the time needs for the dispersion of the discharged water, increase the volume of aquifer affected by the heat loss processes and consequently minimize the time and the space needed for the disappearance of the thermal plume and the restoration of undisturbed temperature conditions. The reduction in plan and temporal extension of the thermal plume would have several benefits minimizing the use of large areas around the buildings to develop the geothermal plants with direct economic benefits. This results are still under more investigation.

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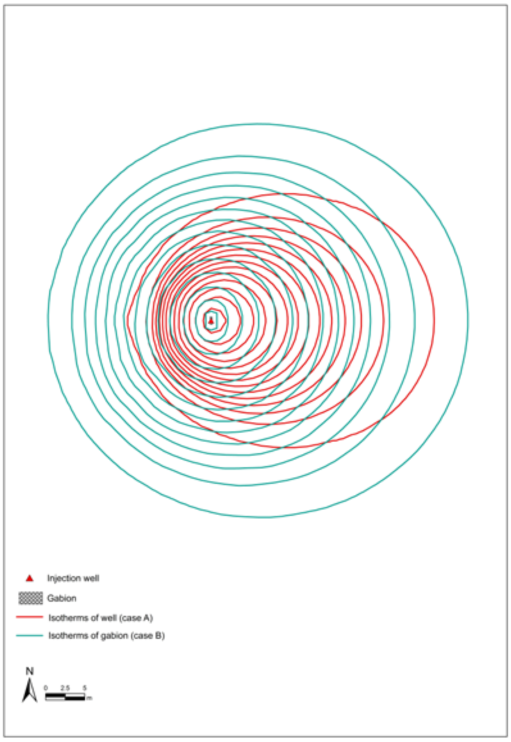


*Fig. 1 – Plan view of the isotherms in case A and in case B.*